Design Curve Generation for 3D SiC Fiber Architecture

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Background

- In recent studies, NASA has shown that there are multiple performance advantages in using 3D architectures for advanced SiC/SiC composites. These advantages primarily arise from the use of thru-thickness fibers that provide composites with *improved delamination resistance, improved impact resistance, and improved thru-thickness strength and thermal conductivity*.

- It was also shown that if the matrix had reduced porosity, key structural and formation properties of advanced SiC/SiC composites are controlled and predictable from the fiber tow geometric characteristics and volume fractions within the fiber architecture.

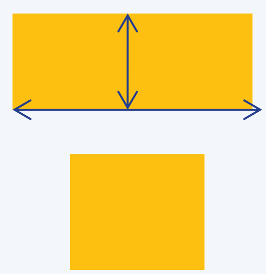
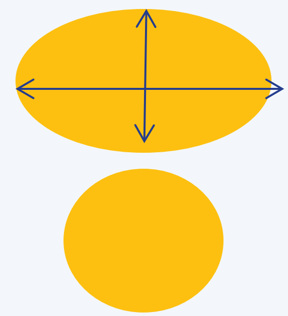
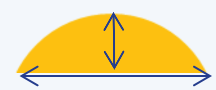
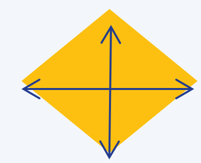
- This important observation initiated in-house studies aimed at developing user-friendly software tools that can be used for designing virtual 3D-woven architectures that will best meet the key fiber-controlled multi-directional property requirements of specific CMC components.

Presentation Outline

- **Describe recent progress in the development of NASA's 3D design tool:**
  - **Development of preform design curves for designing and validating virtual SiC/SiC composite panels containing down-selected 3D modified layer-to-layer architectures of high-stiffness high-performance Hi-Nicalon Type S SiC fibers**
  - **Design curves allow an understanding and prediction of the effects of fiber geometry on key properties of 3D preforms, such as fiber fractions in three directions, preform height, and minimum fiber bend radius to avoid fiber fracture**
  - **Fabrication of the down-selected preforms and validation of the design curve predictions for the key process and geometric properties of the preforms.**
  - **Initial approach for extending the design tool to predict the key multi-directional property of Matrix Cracking Strength (MCS) for SiC/SiC reinforced by these architectures.**

Key Tow Shapes and Dimensions in 2D and 3D Woven Architectures

Assumption: Tows are completely conformable while retaining 60% fiber packing

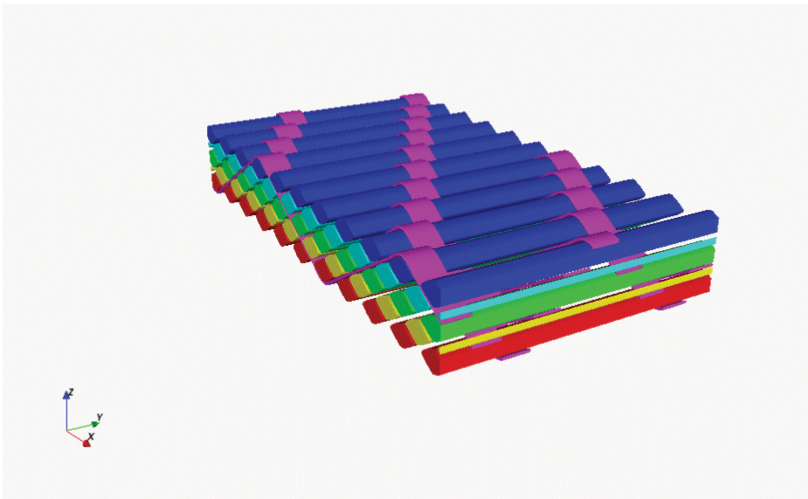
Tow Shape	Rectangular (also square)	Elliptical (also circle)	Half Lenticular	Diamond
Tow Schematics				
Typical Architectures where Tow Shape will appear	3D orthogonal and angle interlock: stuffers and weavers	2D fabric: stuffers	3D orthogonal and angle interlock: surface stuffers	3D angle interlock: warp and fill stuffers
Tow Height (h) x Tow Width (w) for (n) bundled tows **(Total Tow Area = n A_o)**	$hw = 1.0\ (n A_o)$	$hw = 1.3\ (n A_o)$	$hw \cong 1.4\ (n A_o)$	$hw = 2.0\ (n A_o)$

Key Fiber and Tow Modeling Parameters as Measured from 2D and 3D-Woven CMC Micrographs in the Literature

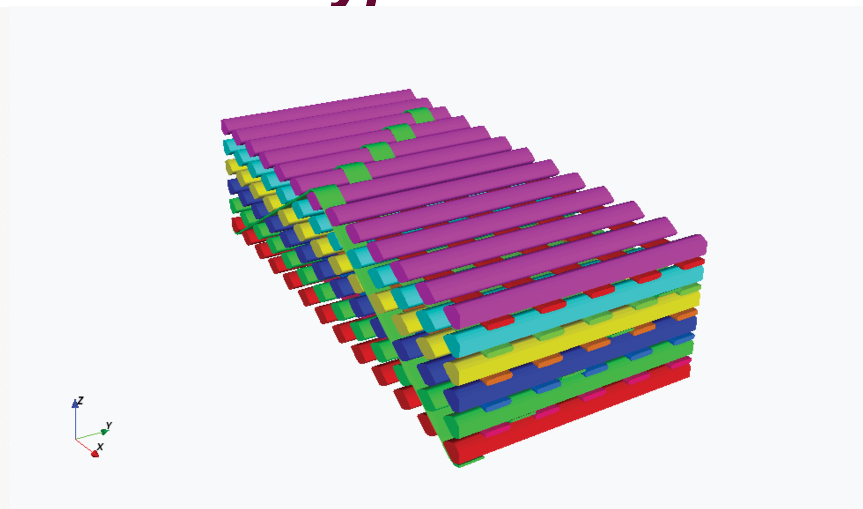
Fiber Type	Sylramic (also iBN)	HNS	HN	ZMI	Nicalon	Nextel 720
Single Tow Fiber Count (N_f)	800	500	500	800	500	400
Avg. Fiber Diameter (d), µm	9.7	12.6	13.7	11.0	14.1	12.5
~ Min. Bend Radius without fiber fracture	1.0 mm	1.0 mm	0.7 mm	0.3 mm	0.5 mm	0.7 mm
~ Fiber Area (A_f) in a Single tow, mm^2	0.059 mm^2	0.062	0.074	0.081 mm^2	0.078 mm^2	0.049 mm^2
~ Min Area of Single Tow (A_0) assuming 0.60 packing factor	0.10 mm^2 (155 mil^2)	0.103 mm^2 (160 mil^2)	0.123 mm^2 (191 mil^2)	0.135 mm^2 (210 mil^2)	0.13 mm^2 (200 mil^2)	0.08 mm^2 (125 mil^2)
~ Natural Lay-Down Width (w*) for (n) Bundled Tows: $w^* = 4d\,(n\,N_f)^{0.5}$	1.10 $(n)^{0.5}$ mm (43 $n^{0.5}$ mil)	1.12 $n^{0.5}$ mm (44 $n^{0.5}$ mil)	1.22 $n^{0.5}$ mm (48 $n^{0.5}$ mil)	1.25 $(n)^{0.5}$ mm (49 $n^{0.5}$ mil)	1.26 $(n)^{0.5}$ mm (50 $n^{0.5}$ mil)	1.00 $(n)^{0.5}$ mm (39 $n^{0.5}$ mil)

Note: Lay-down width (w*) only applies when the tow ends/per/inch allows a tow spacing larger than w*

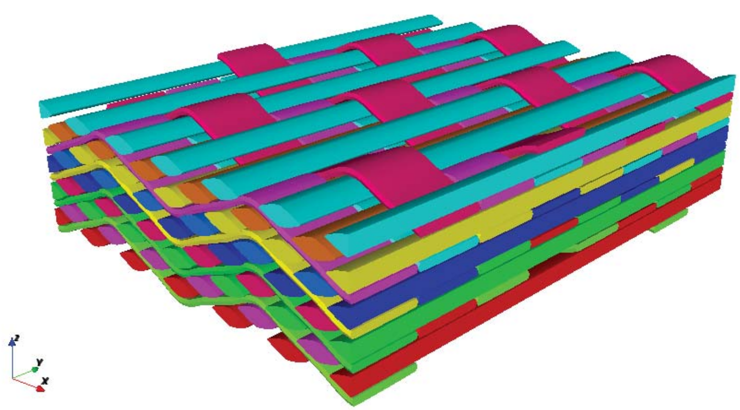
NASA Computer-Based Visualization Tool for Basic 3D Architecture Types



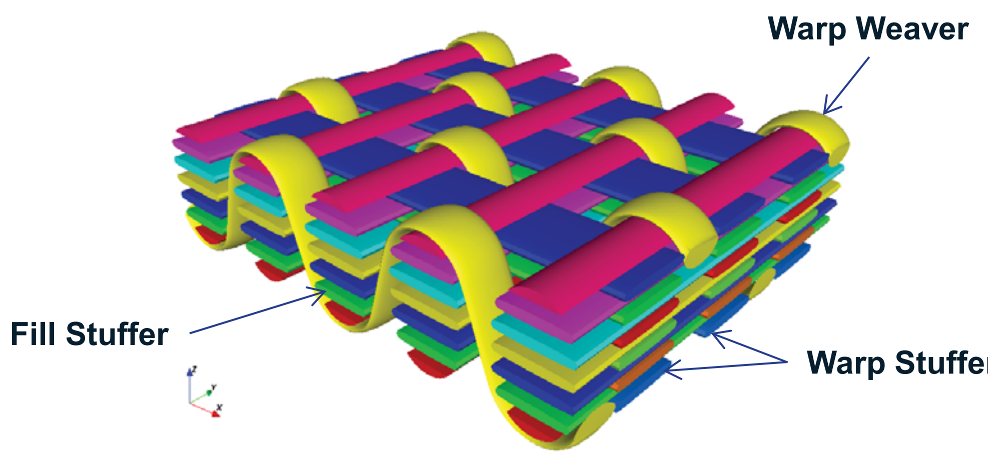
Through Thick Angle Interlock w/o Warp Stuffers



Through Thick Angle Interlock w/ Warp Stuffers



Ply-to-Ply Angle Interlock, TEAM Inc recommendation



3D Orthogonal -1 float

3D Architecture Design Activities and Process Constraints

Objective: **Generate design curves for the key process, geometric, and mechanical properties of 3D architectures for virtual composites based on the following constraints that are applicable to SiC/SiC CMC reinforced by high-performance high-stiffness SiC fibers:**

- **Keep fibers as straight as possible in-plane for highest in-plane MCS and rupture strength**
- **Avoid fiber fracture caused by bending and abrasion of the best stoichiometric SiC fibers:**

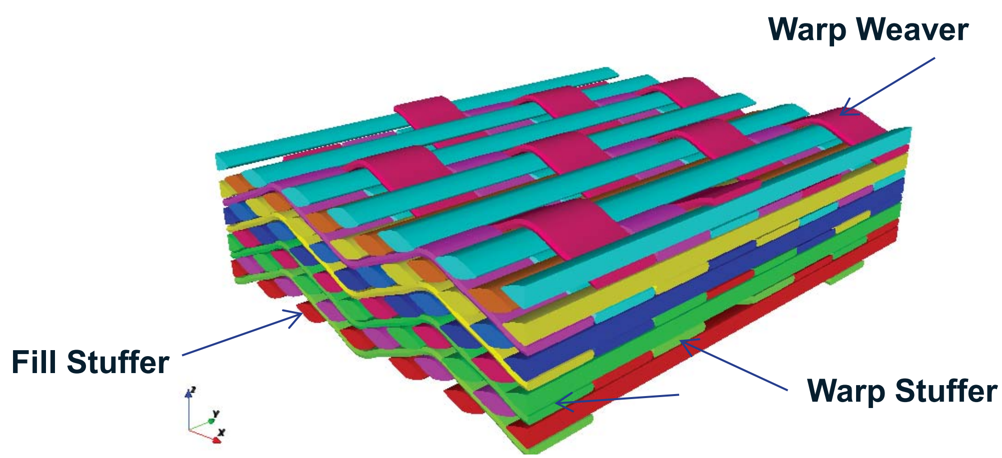
  Warp weaver bend radius > fiber fracture radius

- **Maximize total fiber volume fraction for sufficient multi-directional reinforcement**
- **Assure sufficient fiber content in the x, y, z directions to meet typical component multi-directional structural requirements.**

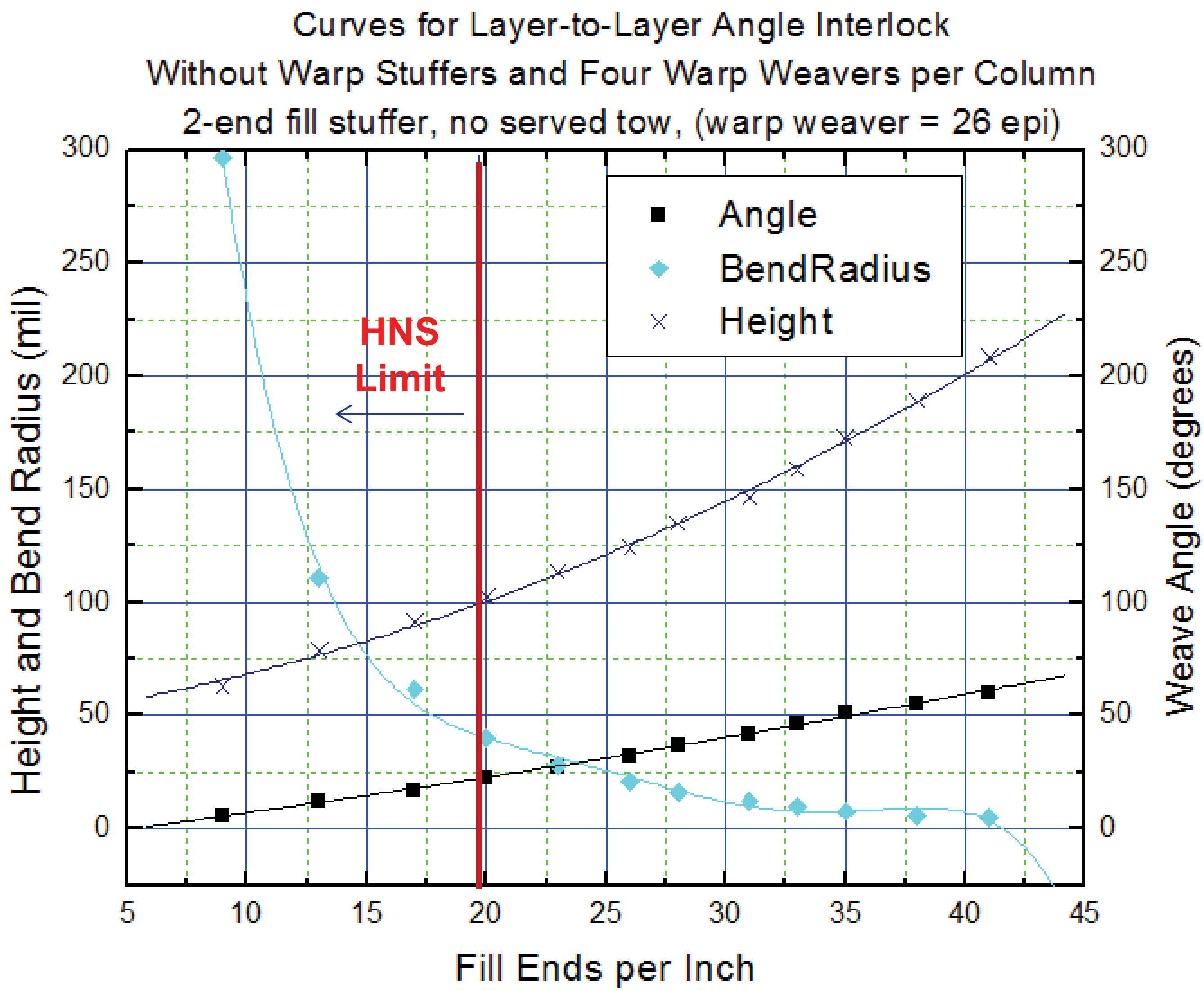
  Key: high effective z fiber fraction for thru-thickness properties

Current Down-selected 3D Architectures for SiC/SiC Composites

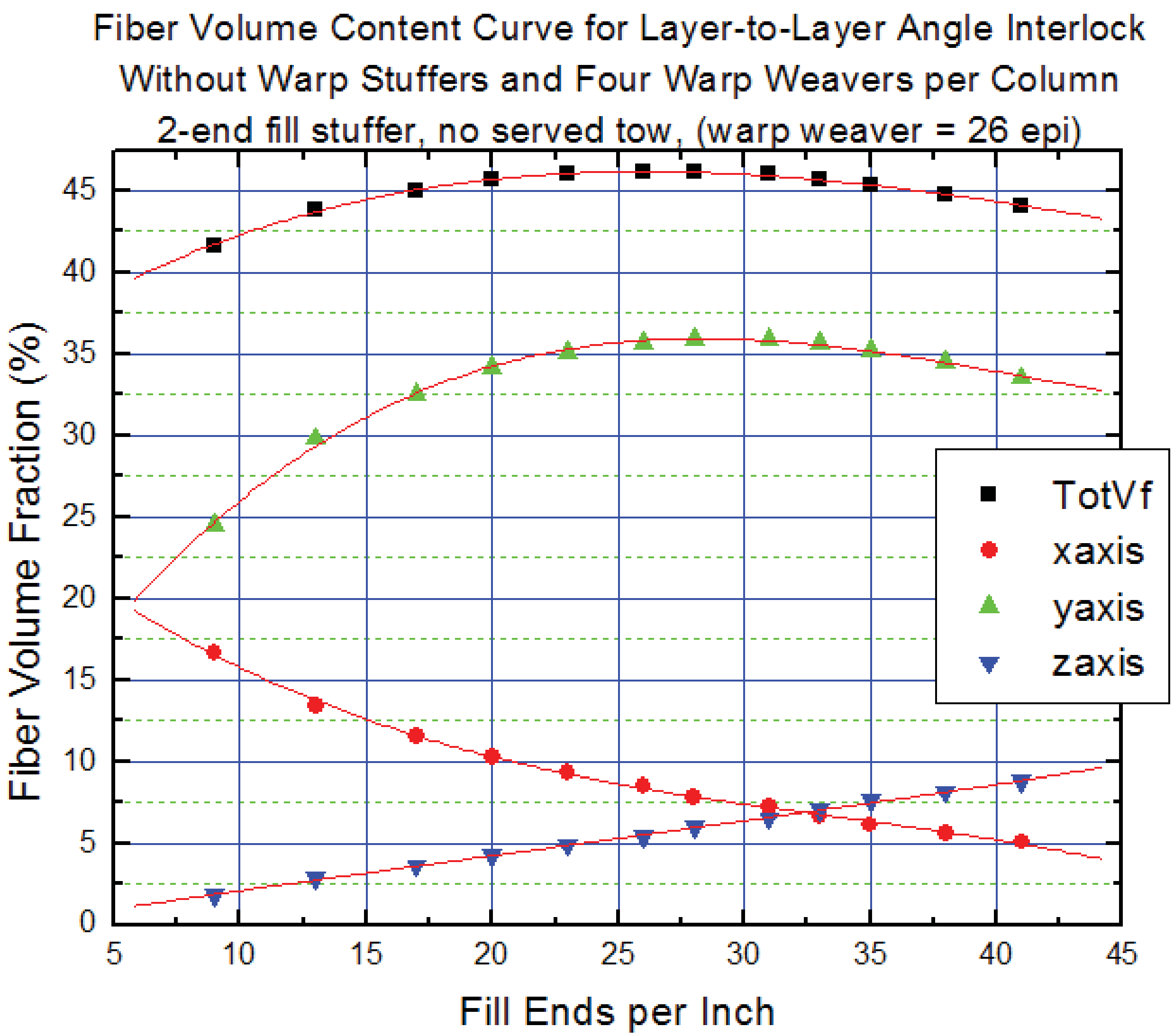
- Based on performance characteristics desired such as total volume content, panel height, tow float, tow bundle, directional fiber volume content, and ease of fabrication, design tool was used to down-select three types of 3D modified layer-to-layer architectures of high-stiffness high-performance Hi-Nicalon Type S SiC fibers.
- Preforms of these architectures were fabricated by TEAM and will eventually be used to fabricate SiC/SiC panels for property evaluation.
- Design tool predictions were compared to those measured on the final preforms.



Process Property Curves for Modified 3D Layer-to-Layer Angle Interlock



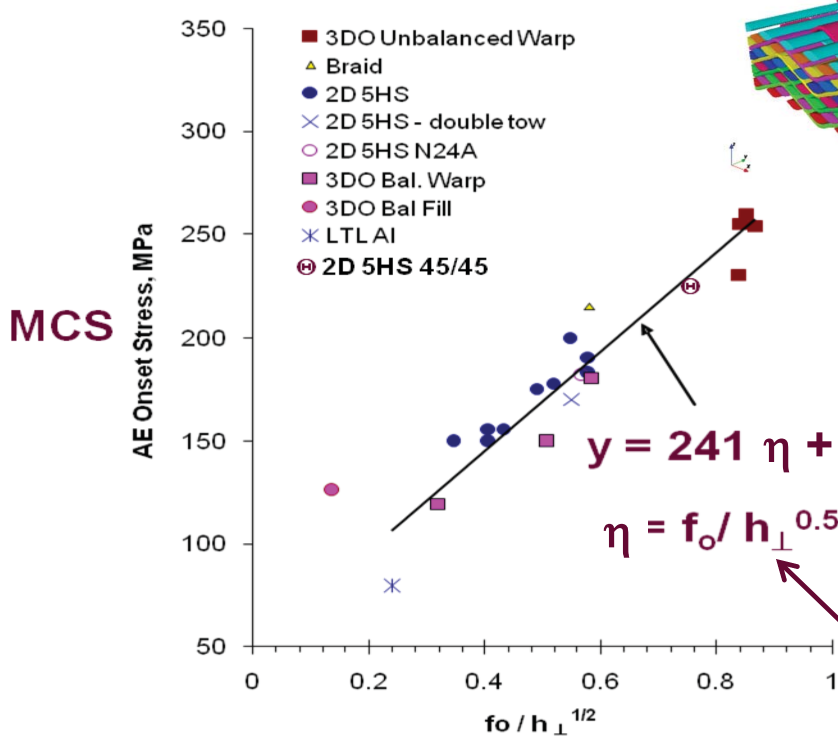
Fiber Volume Curves for Modified 3D Layer-to-Layer Angle Interlock



Design Tool Prediction of T.E.A.M., Inc Preforms

Style Number	Design Number	Weave	Panel ID		Warp per column	Warp columns per Inch		Fills per column	Fill columns per Inch	Panel thickness	Fiber volume by weight
			0039-01-01		4	26		4,5	19.0	0.059	33%
			0039-01-02		4	26		4,5	19.0	0.060	32%
0039-01	1A	Mod L-L	0039-01-03		4	26		4,5	20.0	0.062	33%
Visualization Tool Results (CompGen)											
		Mod L-L			**4**	**26**		**4,5**	**20.0**	**0.060**	**34%**
Visualization Tool Design Property Results											
Weaver Angle	**Vfx**	**Vfy**	**Vfz**		**Bend Radius**						
5.03°	22.4%	11.5%	2.0%		405.1 mils						
Style Number	**Design Number**	**Weave**	**Panel ID**		**Warp per column**	**Warp columns per Inch**		**Fills per column**	**Fill columns per Inch**	**Panel thickness**	**Fiber volume by weight**
			0039-02-01		4	26		4,5	35.0	0.059	46%
			0039-02-02		4	26		4,5	35.0	0.060	47%
0039-02	1B	Mod L-L	0039-02-03		4	26		4,5	35.0	0.062	46%
Visualization Tool Results (CompGen)											
		Mod L-L			**4**	**26**		**4,5**	**36.8**	**0.063**	**42%**
Visualization Tool Design Property Results											
Weaver Angle	**Vfx**	**Vfy**	**Vfz**		**Bend Radius**						
12.28°	16.0%	25.2%	3.5%		104.3 mils						

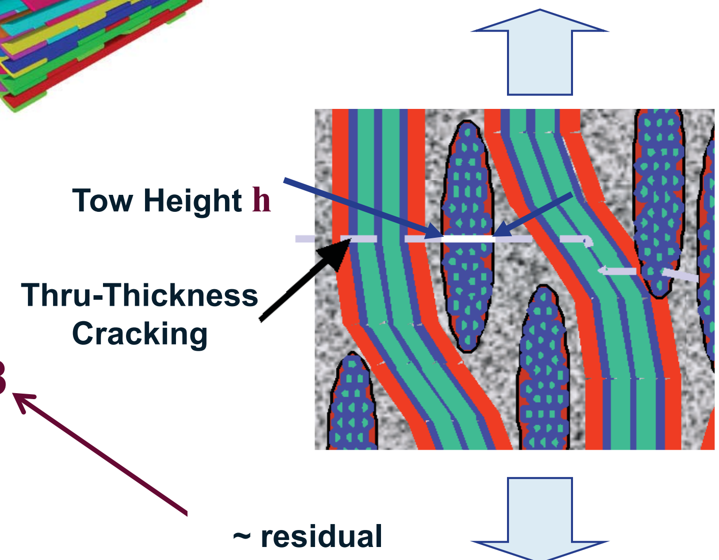
Design Tool* for Predicting and Optimizing Architecture Effects on Matrix Cracking Strength for Dense SiC/SiC



$$y = 241\ \eta + 48$$

$$\eta = f_o / h_{\perp}^{0.5}$$

Architecture recommendation by TEAM Inc.
Modified layer-to-layer



~ residual stress on matrix

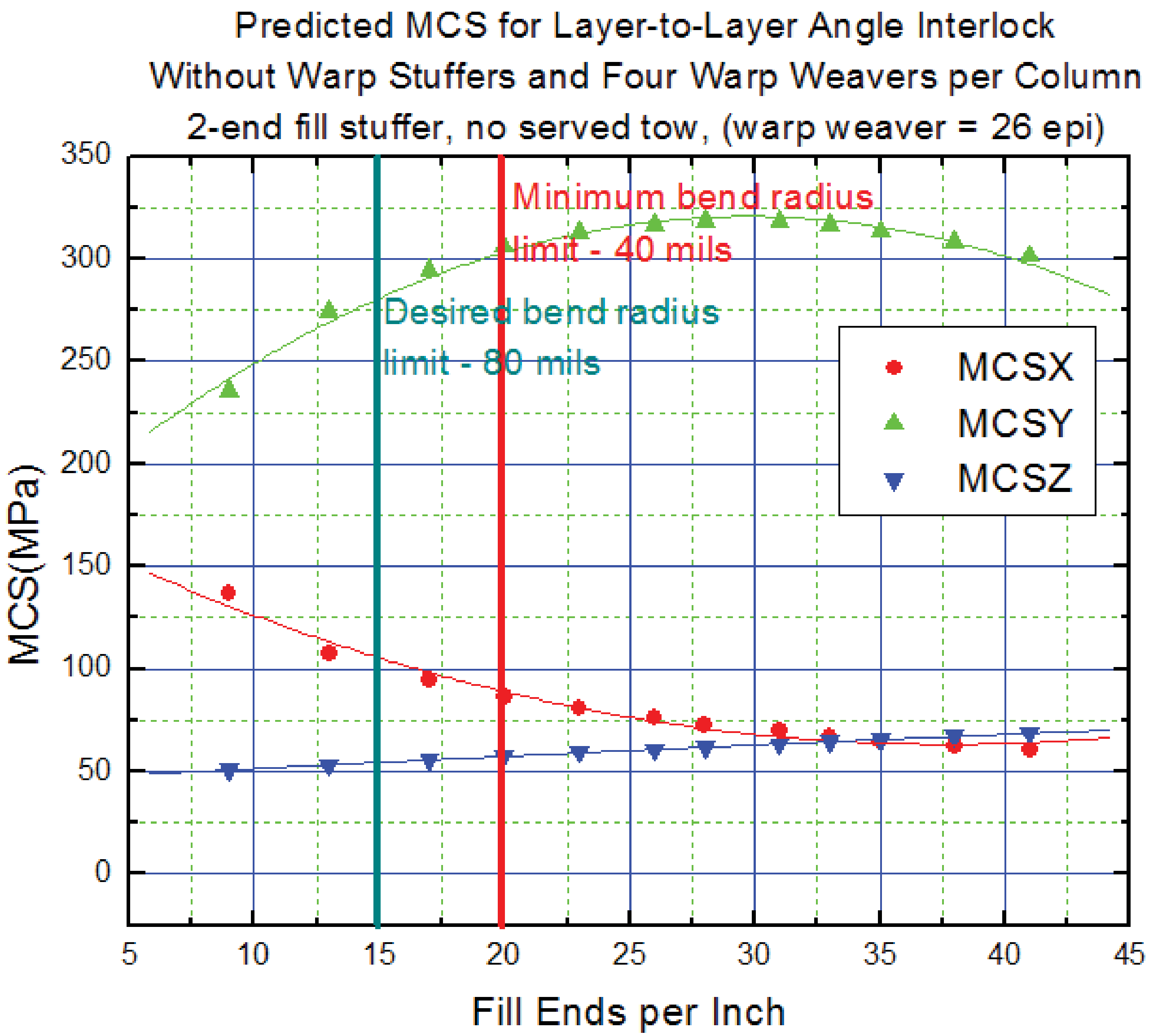
Key Architecture Factors Controlling Multi-Directional MCS:

f_0 = effective fiber volume fraction in test direction *(needs to be maximized)*

$h_{\perp}$ (mm) = maximum height of tows perpendicular to test direction *(needs to be minimized)*

* G. N. Morscher, J. A. DiCarlo, J. D. Kiser, and H. M. Yun, "Effects of Fiber Architecture on Matrix Cracking for Melt-Infiltrated SiC/SiC Composites," Int. J. Appl. Ceram. Technol., 7 [3] 276–290 (2010).

MCS Prediction for Modified 3D Layer-to-Layer Angle Interlock



Summary and Future Directions

- The design tool provides design curves that allow a simple and quick way to examine multiple factors that can influence the processing and key properties of the preforms and their final SiC-reinforced ceramic composites without over obligating financial capital for the fabricating of materials.
- Tool predictions for process and fiber fraction properties have been validated for a HNS 3D preform.
- The virtualization aspect of the tool will be used to provide a quick generation of solid models with actual fiber paths for finite element evaluation to predict mechanical and thermal properties of proposed composites as well as mechanical displacement behavior due to creep and stress relaxation to study load sharing characteristic between constitutes for better performance.
- Tool predictions for the fiber controlled properties of the SiC/SiC CMC fabricated from the HNS preforms will be valuated and up-graded from the measurements on these CMC.